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Superconducting Magnets Used in a Magnetic Bumper/Tether System

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Final Technical Report

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Contract #NAG 9-900

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The proposal presented to NASA for the Regional University Grant, reported on herein, contained two major goals, development of new materials, and a continuation of tests on a magnetic bumper/tether for spacecraft docking.

I. Materials

A. The U/n Method

It was proposed to improve the materials in order to make improved superconducting trapped field (permanent) magnets. In our previous study, the most striking improvement in the material was achieved by development of a new type of pinning center.(1) A small amount of U^{235} was added to the superconductor. This was finely dispersed by chemical techniques, and then irradiated with thermal neutrons to induce the reaction

$$U^{235} + n \rightarrow \text{fission} \qquad \text{Eq. 1}$$

The resulting fission fragments create columnar damage regions about 8μm long and 50 A° in diameter, which act as pinning centers. It is these long thin columnar centers which improve the materials. We refer to this process as the U/n method. We have studied it in the HTS material $YBa_2Cu_3O_{7-\delta}$ (Y123). This year, we performed irradiations at the Texas A&M Reactor on 36 U^{235} samples and 36 placebos, and tested the materials at the Texas Center for Superconductivity at UH. We have also extended the study to include Nd123 and BiSCCO, and have irradiated 7 samples of the former, and four of the latter. We also determined that the residual radiation in a magnetic disk 2 cm diam x 0.8 cm is about 0.2 μc. As a comparison we note that the amount of radioactivity in a commercial smoke alarm is 1 μc. This level of radioactivity is about 10 times below that of previous radiation techniques. Also, the cost of the U/n method is 10-100 times below that of other irradiation methods. The presence of samples in this test with no U, and with U^{238}, allow us to cleanly separate the effects of U^{235}.

J_c of U/n Y123 material is the highest ever observed in a textured system, and it is not yet optimized. During the present grant three experiments have been done in a search for the optimum J_c in Y123. These involved the addition of 0.7, 0.15 and 0.075%U(wt).

Optimization experiments continue on the U/n method. Two variables are controlled, (a) M_U, the total mass of U added (which determines the number of U deposits), and (b) the mass ratio M_U235/M_U238. When we reported last we had reproducible data for M_U=0.3%U(wt). We have now complimented this data with M_U=0.7%, M_U=0.15%, and M_U=0.075%.

There is a 20% improvement in critical current, J_c for M_U=0.15%, and a 20% worsening for M_U=0.7%. (See Fig. 1.) Thus we have developed knowledge that less U is better, while increasing an already world record J_c by an additional 20%. The experiment with 0.075&U(wt) is still being analyzed.

We believe that the U/n method is the most promising on the world scene for producing high J_c, and high trapped field. Using this method, a single grain trapped field magnet 2 cm diam. x 1 cm, at 77K, traps a field of 2.2 Tesla. This is 5 times the field of a very good permanent ferromagnet. Higher fields are available at lower temperatures (e.g., 5 Tesla at 65K). Four such disks trap a field of 8.5 Tesla at 60K.

In June 1997 we received an award from the ISTEC (Japan)/MRS (USA) Program Committee of the International Workshop, Hawaii, for the highest J_c achieved in bulk material.

B. The Method of Chemical U

We reported last year that U underwent chemical reactions in Y123 which act as pinning centers prior to irradiation. We found that the material was formed with atomic constituents $U_3Pt_2Y_5Ba_{12}O_{30}$, within errors.

This year we produced this material in pure form, outside the Y123 matrix. It would not form directly, but we found it would react when Cu was used as a catalyst. We then studied the X-Ray Diffraction pattern (XRD) to identify the material. We compared by XRD the bulk material produced in this way to the trace U compound present in Y123. Agreement of the XRD patterns is excellent. The XRD studies show a cell structure of $(U_{0.6}Pt_{0.4})YBa_2O_6$. This is a double perovskite.

We will study these chemical pinning centers further, and attempt to find the optimum chemical increase in J_c. Our group will study a matrix of points with variables x = % Pt and y = %U. In addition we are investigating chemical substitutes for Pt and U.

The chemical U results are of great interest because they produce excellent magnets with essentially no radioactivity.

C. New International Collaboration

The attractiveness of both the U/n method, and the Chemical U method, has resulted in an exciting collaboration. At UH we will pursue optimization of these methods in Y123 and in Sm123. At ISTEC, Japan, Masato Murakami, Director of Div. VII of ISTEC, will assist us in pursuing Nd123. Prof. Gernot Krabbes, at Dresden, will collaborate with us in the production of *large grain* U/n Nd123. Prof. S.X. Dou of Univ. of Wollongong in Australia will pursue BiSCCO, presently the best candidate for superconducting wire. Prof. Harald Weber of the Atom Institut of the Univ. of Austria (Vienna) will test all compounds. The collaborators were chosen because the material produced by each is probably the best in the world.

A scientist from ISTEC, Japan spent most of the Fall 1997 semester at our UH labs. He taught us how to make large grain Nd123, and we taught him the U/n method. We have now produced the first Nd123, and U/n Nd123 made in our labs. These samples, along with 3 from Dresden, have been irradiated at the Texas A&M Reactor, but are not yet evaluated. (Eventually the trapped field and J_c in U/n Nd123 is expected to significantly improve upon the U/n Y123 results.)

Prof. Dou of Univ. of Wollongong, has learned how to mix U with BiSCCO and avoid spoiling the superconductor. He produced four BiSCCO "tapes," which have been irradiated, but not yet analyzed.

In Y123 we have been able to directly observe the damage done by fission fragments (See Fig. 2.) utilizing TEM.

D. Publications

Papers were presented in Beijing(2,3) and invited papers were presented at the 1997 Internat. Workshop, Hawaii (4) and the Cambridge Univ. Conference on Processing Large Grains (RE)123.(5) One invited paper is written for, and will be presented at the Symposium on Processing and Critical Currents, Wagga Wagga, NSW, Australia, Feb. 1998.(6)

II. Magnetic Bumper/Tether

A. Advances in the Electromagnet

The second goal of the RUG study was continued development of a soft docking device, based upon superconducting trapped field magnets. The system applies to two approaching spacecraft. An electromagnet is mounted on the front of one craft, and an area of superconductor is on the front of the other. As the two craft approach, the superconductor is cooled in zero magnet field, and the electromagnet is turned on.

An experimental apparatus was developed last year to measure the repulsive "bumper" force which occurs as the two craft near each other, and the force which occurs after they magnetically "bounce" off one another. Most prior work on the bumper/tether was done with SmCo permanent magnets simulating the electromagnet. This year the requirements on the electromagnet were explored, and a very favorable geometry developed. The shape of the magnet is known as the "Spiral of Archimedes."

Other work done this year included:

(a) Measurement of the bumper force with the new electromagnet, and our best high quality superconductor. This resulted in world record bumper (i.e., levitation) forces.

(b) Development of our test tower (i) to accommodate the more powerful HTS magnets we have developed, and (ii) to measure stability (transverse) forces.

Fig. 3 shows the dramatic increase in bumper force achieved using a new configuration of HTS, activated by the newly designed electromagnet.

It appears at this stage of development that the magnetic bumper/tether[7,8] will indeed provide a practical docking mechanism, either primary or backup. Funding will be requested from NASA to perform a scale model test, in space.

B. Publications

The development of the bumper/tether was reported at an international conference on superconductivity[7], and at a NASA sponsored conference on applications of levitation[8].

III. References and Publications

1. R. Weinstein, J. Liu, Y. Ren, I.G. Chen, V. Obot, R.P. Sawh, C. Foster and A. Crapo, Invited Paper, "Effects of High Energy Irradiation of MT Y123 on J_c, Trapped Field, Creep, and the Irreversibility Line," Proc. International Workshop on Superconductivity, Kyoto, Japan (June 1994).

2. Y. Ren, R. Weinstein and R. Sawh, Selected Talk, "New Chemical Pinning Center from Uranium Compound in Melt Textured YBCO," Proc. of 5th International Conf. on Materials and Mechanisms of HTS, Beijing, Feb (1997), Physica C, 282-287 (1997) 2275.

3. Y. Ren, R. Weinstein, R. Sawh, and J. Liu, Selected Talk, "Isotropic Short Columnar Pinning Centers from Fission Fragment Damage in Bulk Melt-Textured YBCO," Proc. of 5th International Conf. on Materials and Mechanisms of HTS, Beijing, Feb (1997), Physica C, 282-287 (1997) 2301.

4. R. Weinstein, Invited Paper, "Large Increases of J_c in Textured Bulk HTS Based upon Chemical and Radiation Effects of Uranium," Proc. of the 3rd Joint ISTEC/MRS International Workshop on Superconductivity, Hawaii, June (1997), in compilation.

5. R. Weinstein, Invited Paper, "The Role of Uranium, With and Without Radiation in the Achievement of $J_c \sim 10^5 A/cm^2$ in Large Grain HTS," Proc. of the 1997 Workshop on Processing of Superconducting (RE)BCO Large Grain Materials, Cambridge, UK, July (1997), Journal of Materials Science and Engineering B, (in press).

6. R. Weinstein, Invited Paper, "The Role of Uranium Chemistry and Uranium Fission in Obtaining Ultra High J_c in Textured Y123," Symposium of Processing and Critical Current of HTS, 2-4 February 1998, Wagga Wagga NSW, Australia.

7. D. Parks, R. Weinstein, R.P. Sawh, and G. D. Arndt, "A Magnetic Bumper Tether System Using ZFC Y123," Proc. of the 1995 International Workshop on Superconductivity, pg. 148, Wailea, Maui, Hawaii (June 1995).

8. R. Weinstein, D. Parks, R-P Sawh, V. Obot, J. Liu and G. D Arndt, "A Magnetic Bumper-Tether System Using ZFC Y123, " Proc. of the 3rd International Symposium on Magnetic Suspension Technology (NASA, NHMFL) Tallahassee (December 1995)

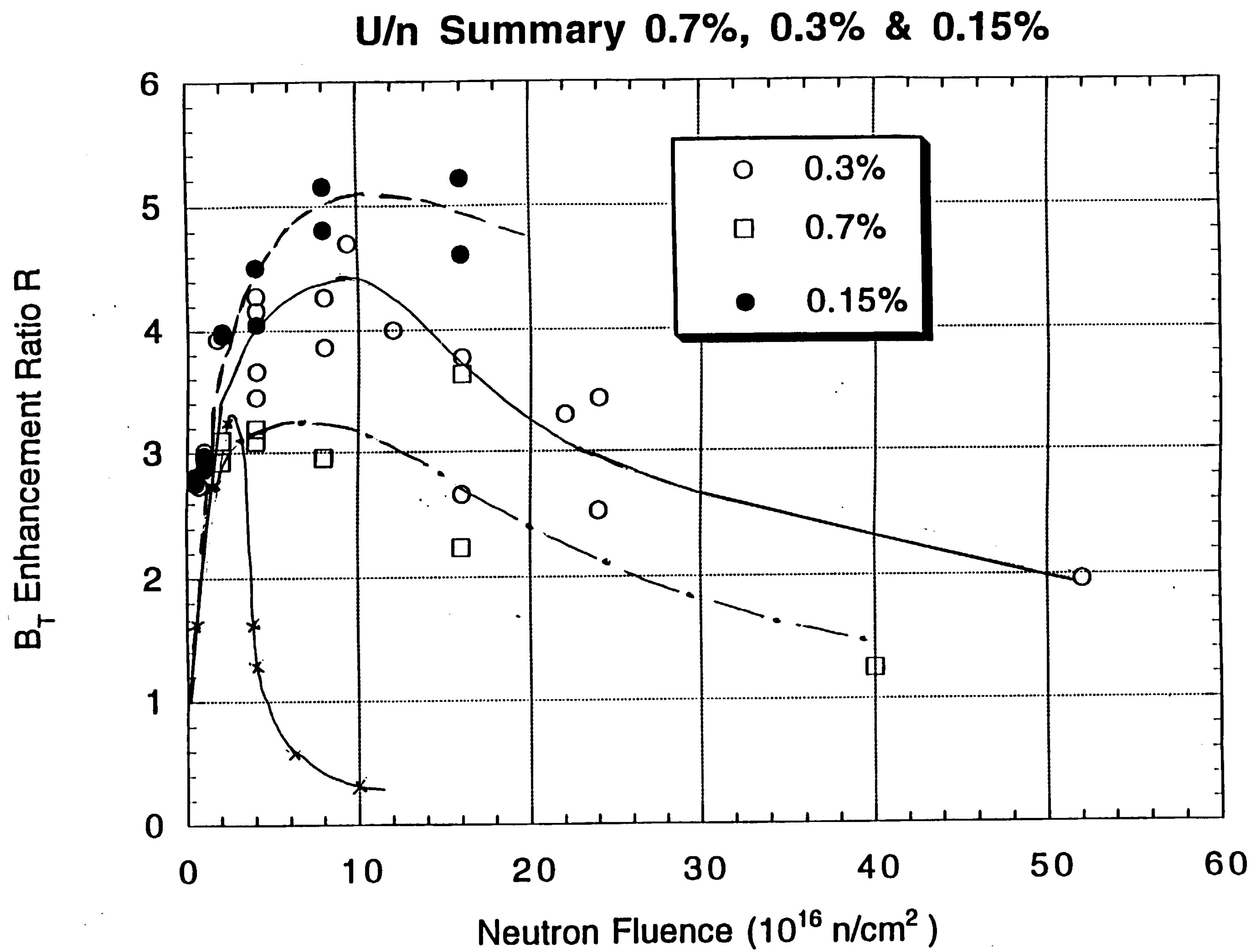

Fig. 1. R_M vs. neutron fluence, F_n, where $R_M \equiv B_{trap}(F_n)/B_{trap}(0)$. Four experiments are shown, three with M_U=0.15%, 0.30% and 0.70%U(wt). The fourth (marked X) compares U/n results to results for simple parallel columns created with 5GeV Xenon ions.

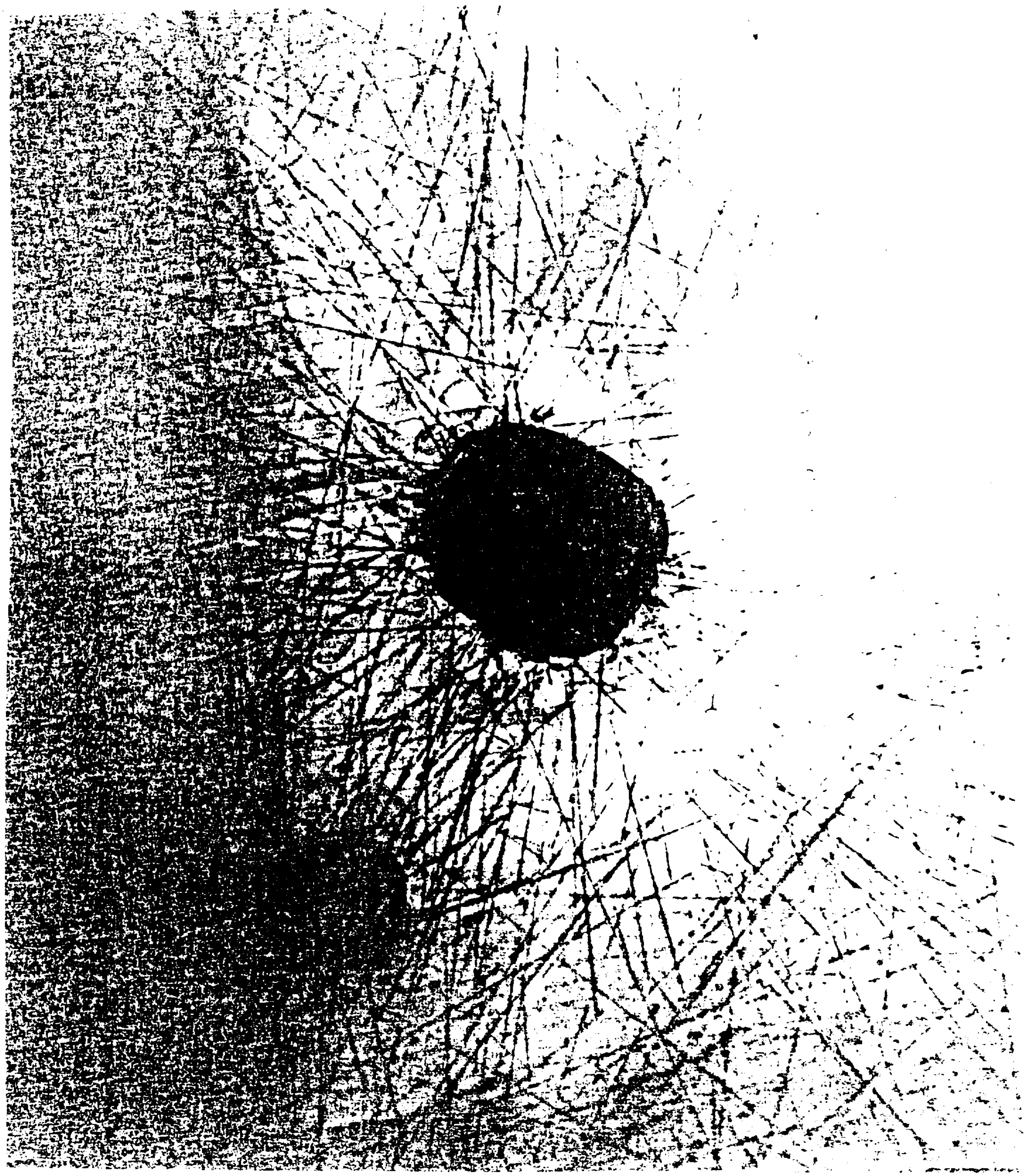

Fig. 2. TEM study of damage caused by fission fragments from U235. Damage tracks all originate from a deposit of $(U_{0.6}Pt_{0.4})YBa_2O_6$ (black areas), but some deposits are below the depth of view.

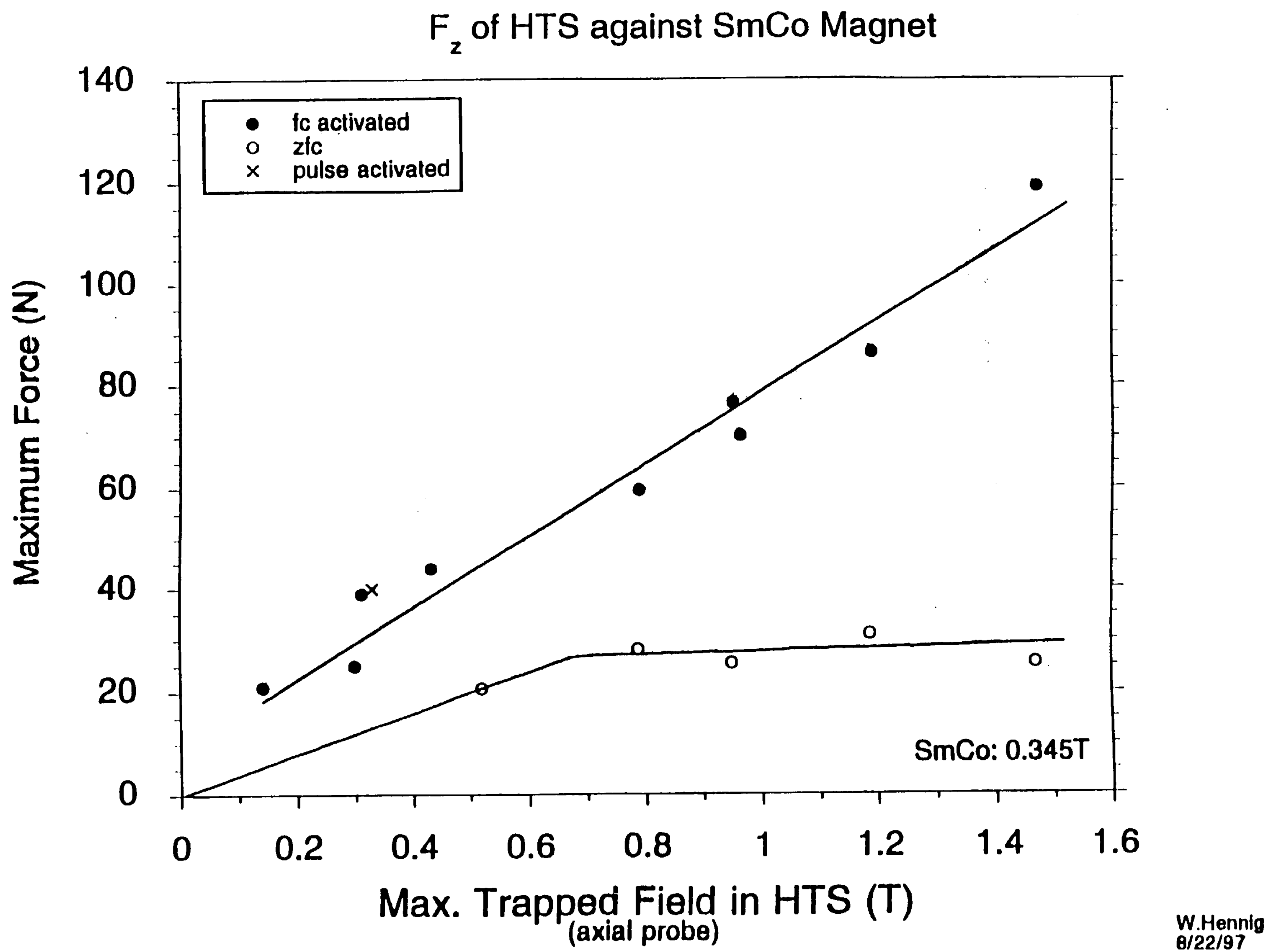

Fig. 3. Bumper forces vs. quality of HTS as measured by trapped field. Open circles are old configuration, in which the HTS is cooled in zero field. Filled circles are new configuration in which the HTS is activated using a pulsed magnet.